Space Weather Technical Forecast

Issued on Friday, 15 December 2023 at 13:18 Local

This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: High activity with further M-flares likely, and chance of X-flares (R1-R3). G1 Minor Storms possible from CME arrivals Days 1-2 (15-16 Dec). Initial assessment of X-flare CME gives a chance of G1-G2 early Day 3 (17 Dec).

Analysis of Space Weather Activity over past 24 hours

Solar Activity: High with peak flare X2.8 from AR3514 in the northwest disc, peaking 14/1702 UTC. This was the largest flare of SC25 so far, and the largest since Sep 2017. Three further M-flares were also observed from this region including a double-peaked M6.2/6.8 flare peaking 15/0734 UTC. This is a complex and moderately sized region approaching the northwest limb, which saw ongoing growth and development through the last 48 hours. Since the X-flare and subsequent M-flares, development of the region has continued and further flares are possible. This is one of eight other active regions on the disc, however the other regions are largely smaller and simpler, with no significant growth observed.

Three CMEs were observed in the last 24 hours with potential Earth-directed components. The first was due to a filament eruption across the north of the Solar disc, starting 14/1109 UTC, and the second was from the X2.8 flare. These have been assessed, with the X2.8 flare CME likely sweeping up the weaker filament eruption, with an arrival time estimated as early Day 3 (17 Dec). The M6.2/6.8 double-peak flare from AR3514 also produced a CME, with analysis awaiting. Any other CMEs in the last 24 hours have been assessed as not having earth-directed components

Solar Wind / Geomagnetic Activity: Solar winds were initially indicative of the tail end of a passing weak CME, which had arrived late on 13 Dec. Speeds, as measured by ACE at L1, persisted at background, near 350 km/s, with density largely below average. A sudden shock was observed at 15/1057 UTC, indicative of the arrival of a possible CME. Wind speeds increased to around 400 km/s with density increasing to Above Average. The interplanetary magnetic field (IMF), Bt, was Weak, initially around 8nT, but easing to around 4-6nT. After the CME arrival mentioned, the IMF rose to Moderate-Strong levels of around 13-18nT. The north-south component, Bz, was generally negative (southward) and Weak, around -3 to -6 nT. It then increased to moderate after the CME arrival, varying between +4 and -12nT. Phi angle was generally positive (away from the Sun). Geomagnetic activity was initially Unsettled (Kp3), but eased to be Quiet from 14/1500 UTC (Kp1-2).

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux was at Background levels until 14/1900 UTC, then rose to be slightly above background peaking 2.84pfu at 15/1150 UTC. This was in response to the X2.8 and following M-flares from AR3514. GOES16 high energy (greater than 2MeV) electron flux was also background. The 24-hour fluence was below the Active threshold (1e8 integrated pfu). The observation at 15/0000UTC was 1.19e6 integrated pfu.

Four-Day Space Weather Forecast Summary

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Met Office Space Weather Technical Forecast

Solar Activity: Moderate to High activity expected with the ongoing likelihood of M-class (R1-R2) flares and a chance of further isolated X-class (R3) flares from AR3514. This risk recedes later Day 3 and through Day 4 (17-18 Dec) as the region moves further around the far-side.

Solar Wind / Geomagnetic Activity: There are two Earth-directed CMEs arrivals expected. The first from 13 Dec filament eruption near AR3514, early on Day 2 (16 Dec), and the second from the X2.8 flare on 14 Dec, early on Day 3 (17 Dec).

The observed CME arrival early on Day 1 (15 Dec) may be the first forecast CME arriving early, but perhaps more likely is as a result of an un-forecast CME. As such, this CME is kept in the forecast to arrive early on Day 2, but with slightly lower confidence. The second CME has had an initial assessment, with an arrival time estimated for early Day 3 (17 Dec). Otherwise CH79/+ may bring a weak enhancement on Day 1 (15 Dec) with solar winds perhaps rising to around 450 km/s, while CH82/+ has the potential to enhance winds on Day 4 (18 Dec), although this is very low confidence.

Overall, geomagnetic activity is forecast to be Quiet to Unsettled at first, rising to Active and possibly to G1/Minor Storm levels, under the influence of the recent CME arrival, as well as any weak coronal hole enhancements on Day 1 (15 Dec). The CME arrival early on Day 2 (16 Dec) brings a chance of a spell of Active to G1/Minor Storm intervals. The CME arrival on Day 3 (17 Dec) is less certain, but could bring G1-G2 Minor to Moderate storms. Another coronal hole fast wind may arrive on Day 4 (18 Dec), with Unsettled to Active intervals possible.

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is currently on a slow rising trend, and may approach the S1 Minor Radiation Storm threshold Day 1, with a slight chance of exceeding this. There is also a chance that further significant flares from AR3514 will bring a risk of proton flux rising above the S1 threshold. High energy electron flux, as observed by GOES16, is currently at background. Background flux is likely to persist until after any CME influence recedes, either later Day 3 or Day 4 (17-18 Dec). Flux may then rise with a chance of reaching Moderate, perhaps High by the end of Day 4. The associated 24 hr electron fluence is expected to remain below the Active threshold.

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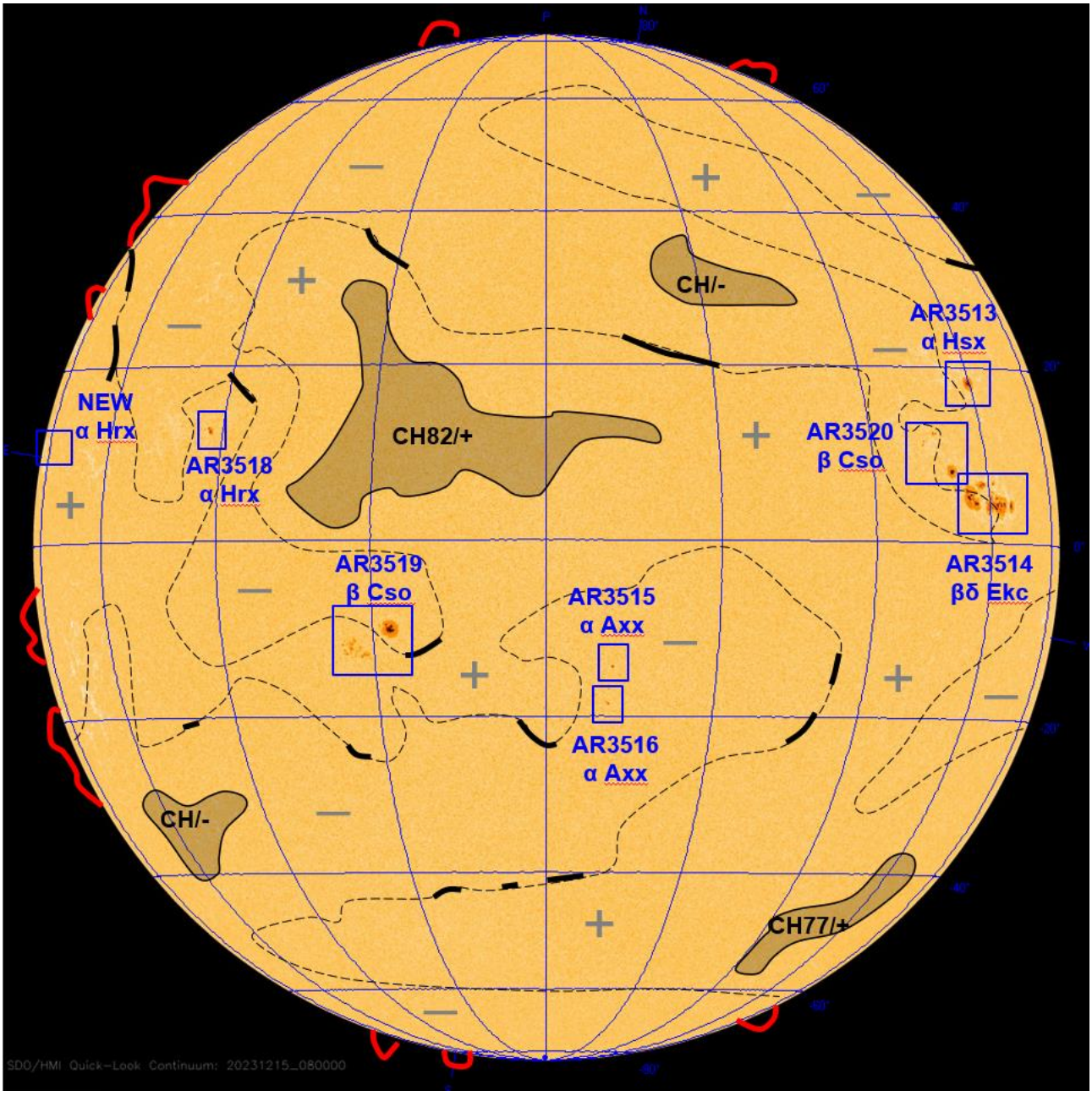
Figure 1. Solar Analysis Valid 15/0800 UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

A shock was observed in the solar wind and magnetic fields at L1, as a result of a possible CME arrival. It is currently uncertain as to the origin of this CME, abut its not out of the question it is as a result of a missed forecast, or even an early arrival of one of the forecast CMEs mentioned below.

There are a number of possible Earth-directed CMEs. The X2.8 flare from AR3514 at 14/1702 UTC produced a moderately fast CME which has had a preliminary assessment as having an Earth-directed component, likely arriving early on Day 3 (17 Dec). However SOHO imagery remains unavailable for this event, so this analysis used only Stereo A coronagraph images. This leads to low confidence in this analysis, and further updates are possible.

The second CME is from a filament eruption near AR3514 on 13 Dec and is expected to arrive early Day 2 (16 Dec). Any impact is likely to be limited due to the faint nature of the CME.
A further weak CME was observed early on 14 Dec. This was from a filament eruption off the north disc starting around 14/1109 UTC. This has been assessed, and looks to be cannibalised by the arrival from the X-flare CME.
The M6.2/6.8 double flare from AR3514 at 15/0734 UTC produced a CME, with assessment awaiting imagery, although its more westerly location suggests that the bulk of the CME should pass ahead of Earth orbit.

Otherwise enhancement is possible from the arrival of any fast wind from CH79/+ on Day 1 (15 Dec) This is a very small feature in the southwestern quadrant, having recently reduced in size in SDO imagery. However, as a larger feature when in centre disc, the associated fast wind still has a chance to give a weak enhancement. This is later than originally forecast, with expected speed of around 450 km/. Confidence is low however, as this feature is not present in Enlil, which is currently overestimating the influence of a southern coronal hole CH77/+. This feature may also be lost in the current CME arrival. CH82/+ has a westwards extension that may then enhance the solar wind Day 4 (18 Dec), however this is very low confidence at this point.

Overall, the geomagnetic forecast is low confidence, with Quiet to Unsettled conditions at first, possibly rising to give spells of Active, perhaps even G1/Minor Storm, under the influence of the recent CME arrival. as well as any weak enhancement from CH79/+. The first forecast CME arrival may give a spell of Active to G1 Minor Storms on Day 2 (16 Dec). The second CME arrival is low confidence at this stage, however given the current preliminary analysis (which may still be updated if imagery becomes available) there is a chance of G1-G2 Minor to Moderate storms early Day 3 (17 Dec). A return to mainly Quiet is likely into Day 4 (18 Dec), perhaps increasing again to Unsettled to Active with any fast wind enhancement from CH82/+.

Geo-Magnetic Storm	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability (Exceedance)			(%)	(%)	(%)	(%)
Minor or Moderate	G1 to G2	No	10	40	40	10
Strong	G3	No	1	15	15	1
Severe	G4	No	1	2	2	1
Extreme	G5	No	1	1	1	1

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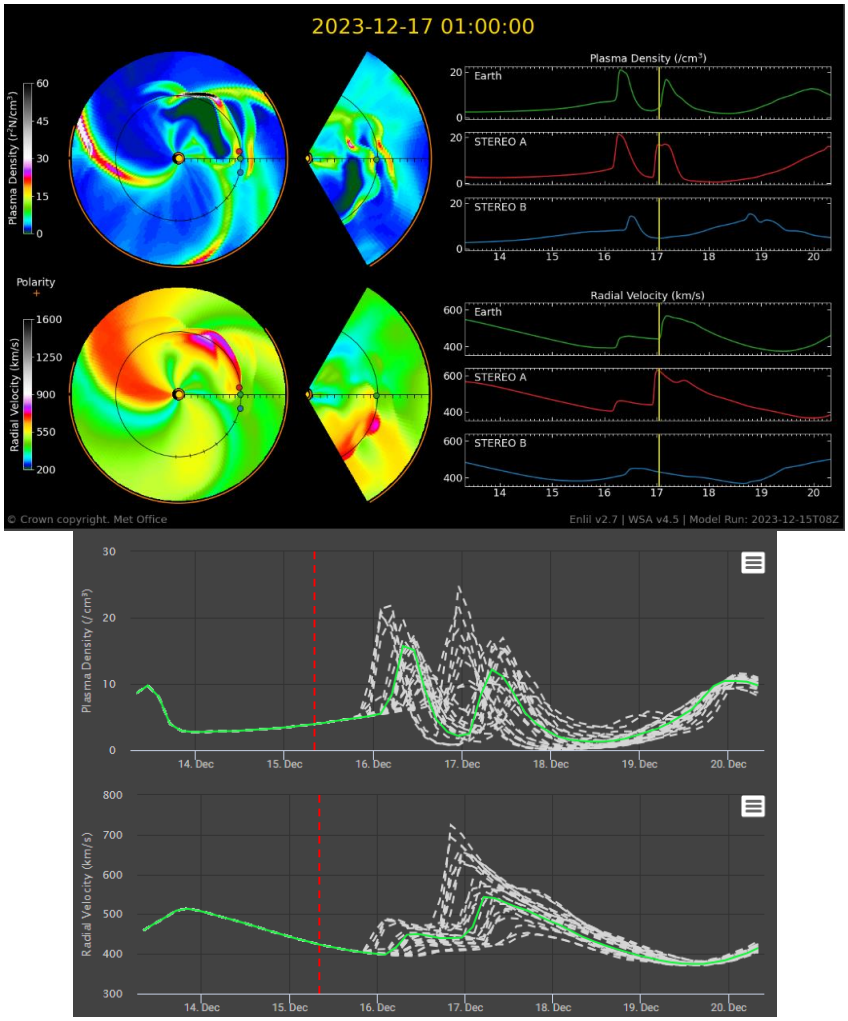
Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
13/0555	Partial	Filament nr AR3514	NW	530 km/s	Early 16 Dec	Low confidence
14/2112	Full	X2.8 from AR3514	NW	974	Early 17 Dec	Lack of imagery means low confidence in fit. May be adjusted.

Figure 2: MOSWOC Enlil and emsemble



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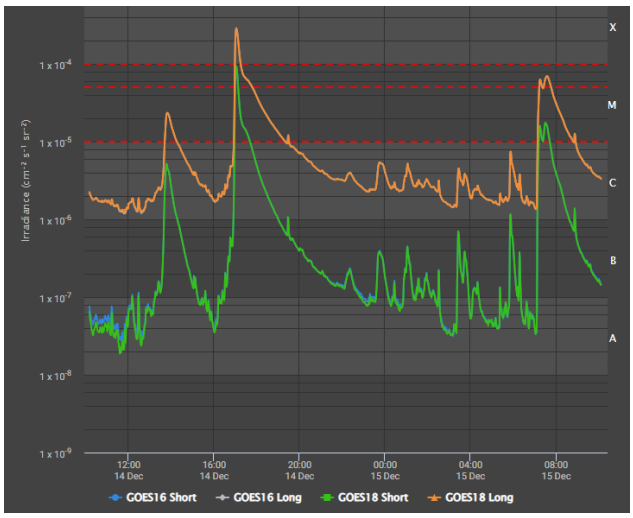
Radio Blackouts - X-Ray Flares:
Moderate to High activity is forecast, with the ongoing likelihood of M-class (R1-R2) flares and a chance of further X-class (R3) flares from AR3514.

This region is a complex and moderately sized sunspot on the northwest disc. Much of the sunspot was initially connected in one large penumbra, but there has been a separation between the main trailer and leader spots over the past 12hrs or so. SDO imagery, such as aia-171, continue to show a complex pattern of looping, although some of this is likely the recovery after yesterdays X2.8 flare event and the M6 flares earlier this UTC day. Given the position of the region, this will become more difficult to analyse through the period as it moves further west. Furthermore, while near limb far-sided flares can be visible Earth-side, the potential for strong flares will gradually decline through Days 3 and 4 (17-18 Dec) as this region moves over the northwest limb and further onto the far-side.

There are a total of eight sunspot regions on the disc, with one unnumbered, however the other regions remain smaller and simpler with no notable growth, perhaps with the exception of AR3519 which has seen some small growth of intermediate spots.

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	Yes	70	70	60	50
Very Active	R3 to R5 X Class	Yes	30	30	20	5

Figure 3: GOES-16 & -18 X-ray flux



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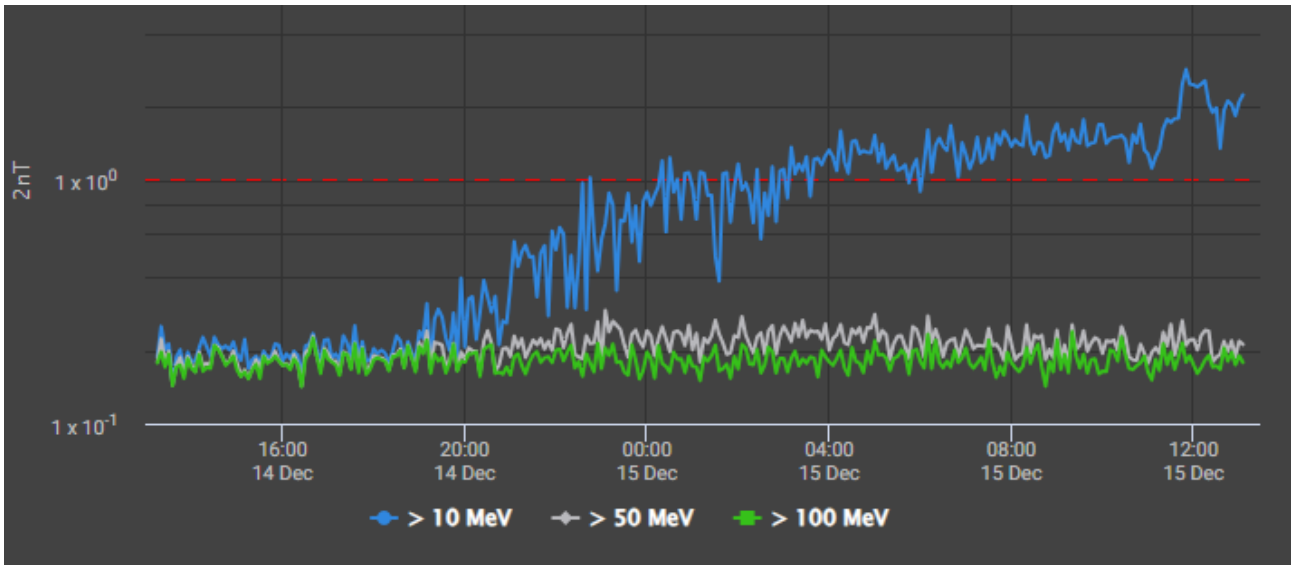
Solar Radiation Storms - (High Energy Protons):
The high energy (greater than 10MeV) proton flux observed by GOES16 has risen above background after the X2.8 flare from AR3514, but currently remains below the S1 Minor Radiation Storm level. This flux will have the potential to continue rising early Day 1 (15 Dec) with the M-flares that occurred, but will likely peak below the S1 level with only a chance of exceeding it. However, given its location on the northwest disc further significant flares from AR3514 will bring a chance of reaching this level through the period. While the region will rotate over the limb during Day 3 (17 Dec), any far-side flares Day 4 (18 Dec) will continue to give a risk of high energy protons.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	≥ S1	No	30	25	25	20
Very Active	≥ S3 *	No	5	5	5	5
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

Figure 4: GOES-16 Proton flux



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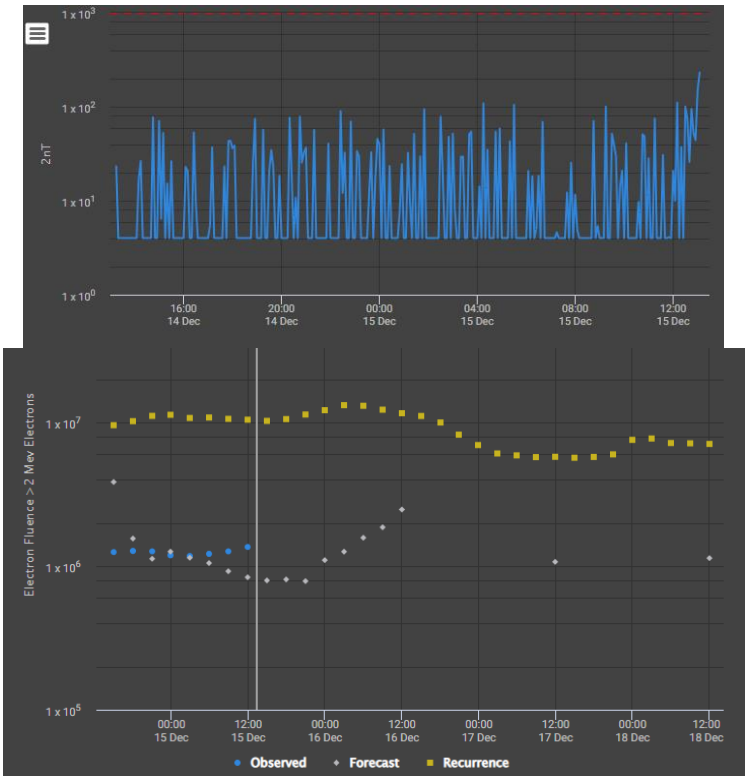
High Energy Electrons Event (≥ 2MeV):
High energy electron flux, as observed by GOES16, is currently at background. The timing and strength of solar wind enhancement from CH79/+ is low confidence, but is currently expected to be relatively weak, occurring Day 1 (15 Dec). This will limit the extent of any increased flux in the Van Allen Belts. Furthermore, the arrival of two CMEs on Days 2-3 (16-17 Dec) are likely to decrease these values further, with the Van Allen belts compressing inward. As solar pressure eases, with any CME influence declining, the observed flux may respond by increasing to Moderate, with a chance of peaking at High by Day 4 (18 Dec).

The associated 24-hour fluence is expected to remain below the Active threshold, as indicated by REFM, although this model doesn't take account of either the fast wind arrival or CME impacts. There is a slight chance that CME enhancements result in Active fluence by the end of Day 4 (18 Dec).

GEO Electron Environment Probability (Exceedance)	Level (cm^{-2} sr^{-1} day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ 2 MeV ≥ $1x10^8$**	No	1	1	5	20
Very Active	**≥ 2 MeV ≥ $1x10^9$**	No	1	1	1	1

Figure 5: GOES-16 Electron flux and REFM



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